QUAKESIM Understanding Earthquake Processes

Remote Sensing | Computational Infrastructure | Pattern Informatics

Computational Infrastructure for Mitigating Earthquake Hazard
by Integrating and Modeling GPS, InSAR, Seismicity, and Fault Observations

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QUAKESIM

What is QuakeSim?

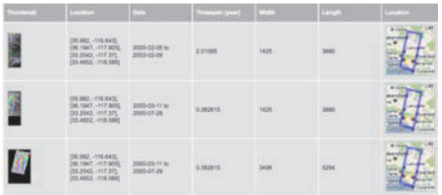
- A project to integrate distributed heterogeneous data sources into a computational modeling and data pattern analysis exploration environment
- Focus is on the interseismic part of the earthquake cycle
  - Crustal deformation and behavior pre-, co-, and post-earthquake
  - Not earthquake waveforms (the shaking part)
- Environment for modeling and understanding of earthquake and tectonic processes with a goal of improving earthquake forecasting
- Make NASA crustal deformation, seismic and geologic data, and various earthquake simulation models available to the broader earthquake science community
  - Prepare for large volumes of NASA data

QuakeSim: Increasing Accessibility and Utility of Spaceborne and Ground Based Earthquake Fault Data

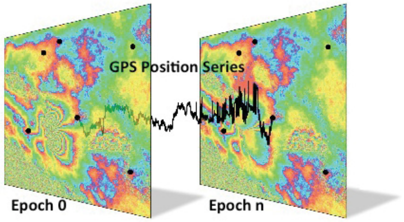
Multidisciplinary and multi-institutional

Geology
Lisa Grant (UC Irvine)

Databases
Dennis McLeod (USC)



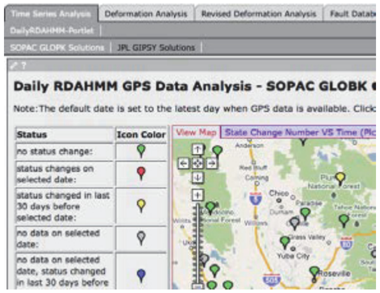
Science, Models, and Data Analysis
Andrea Donnellan, Jay Parker,
Maggi Glasscoe, Greg Lyzenga (JPL)



Grid Computing
Geoffrey Fox (Indiana U)

Future Grid

Web Services
Marlon Pierce (Indiana U)



Pattern Analysis
John Rundle (UC Davis)
Robert Granat (JPL)

High Performance Computing
Walter Brooks (NASA Ames)

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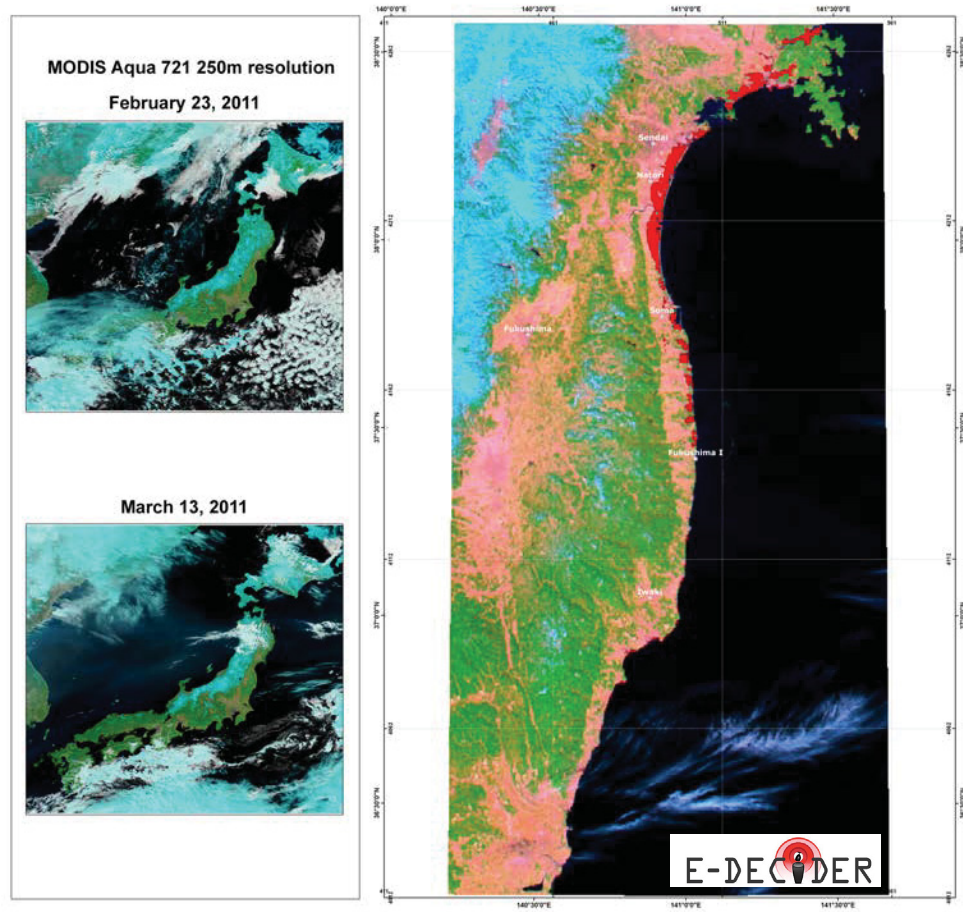
Earthquake Science Data Deluge

- Rapidly increasing data sizes
- Data storage
  - PB/year for InSAR
  - TB-PB/year for model runs
  - 1000s of solutions for 1000s of stations
- Focus on geospatial, environmental data sets
  - Data from computation and observation
- Data, data processing, and modeling pipelines are inseparable

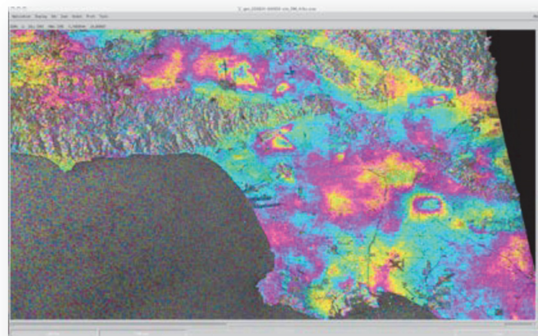


Science is Maximized through Data and Interface Standards

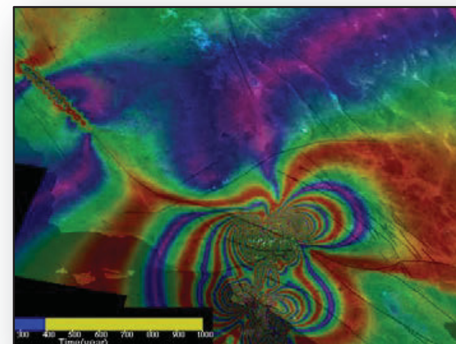
Just some of the QuakeSim interfaces

UAVSAR Solutions

InSAR Analysis



Southern California Earthquake Center Simulators Group



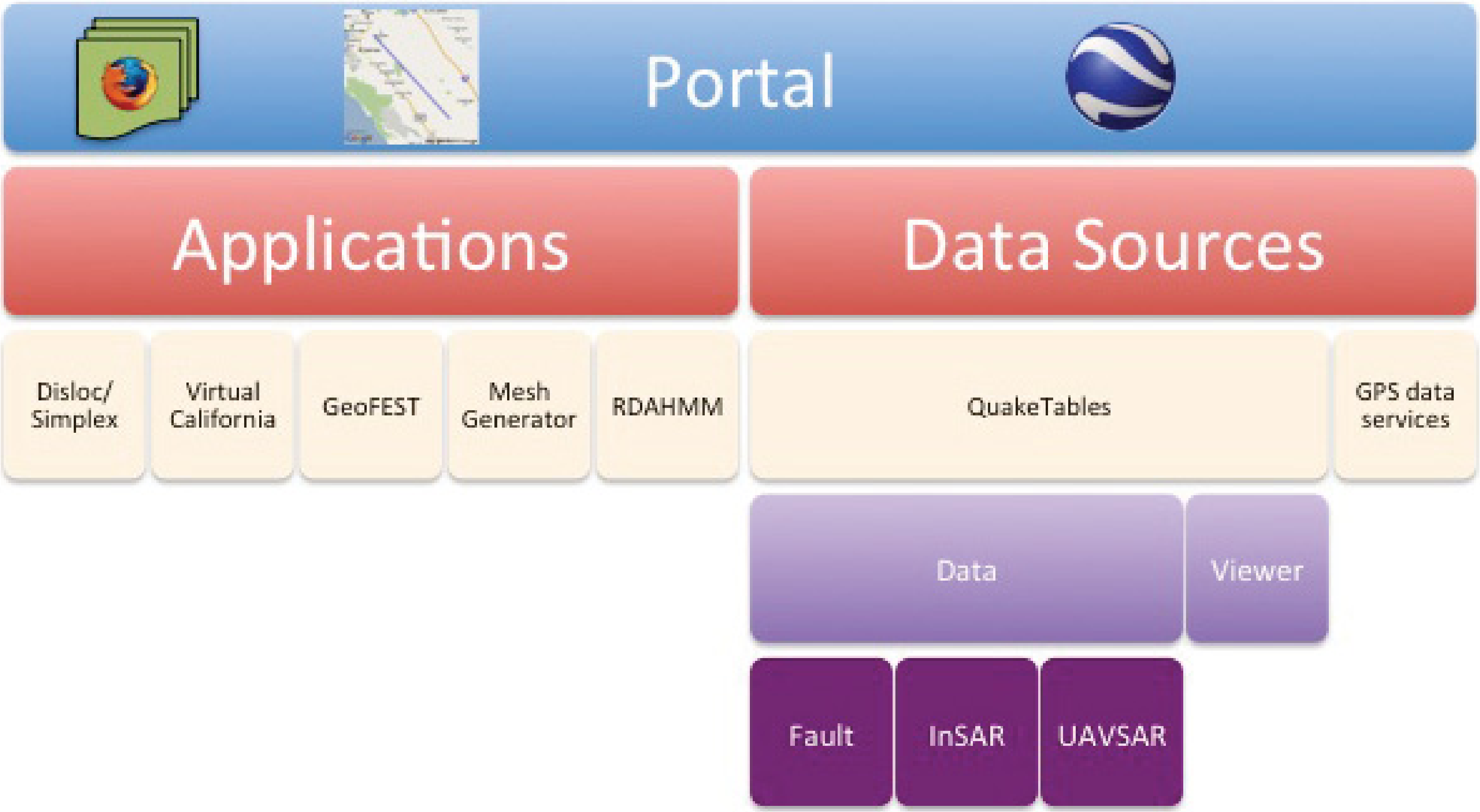
GPS Solutions

APEC Cooperation for Earthquake Simulation

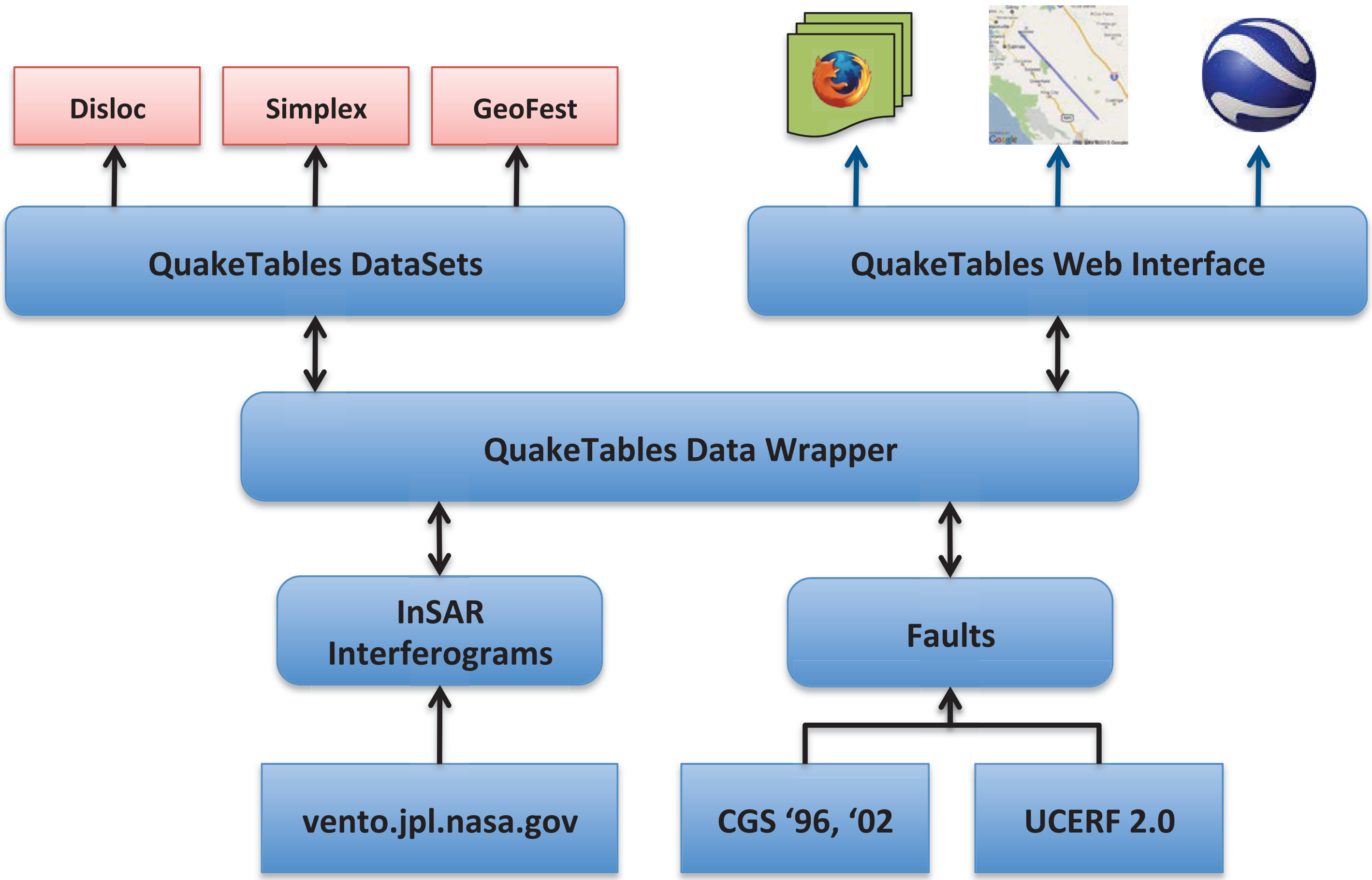
Decision Support

E-DECIDER

QuakeSim Architecture:
Integrating Multiple Data Sources and Applications

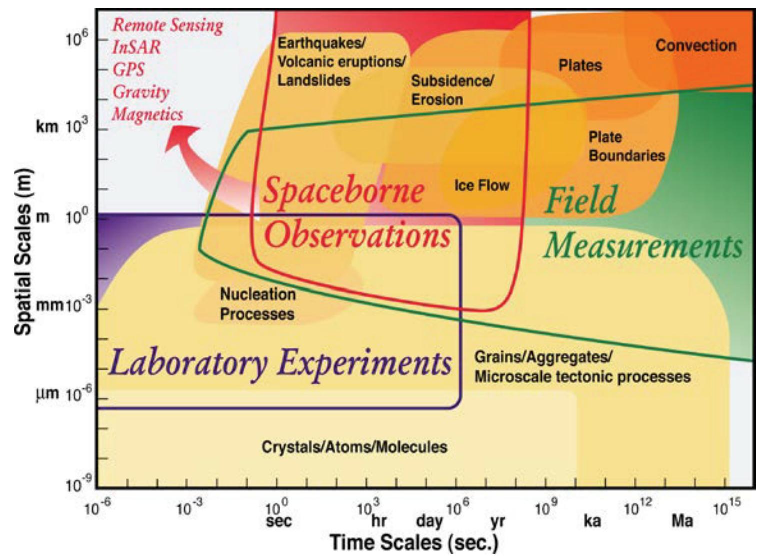


QuakeTables Architecture:
Integrating Multiple Data Sources



Widely Distributed Data Sources Cover Different Time and Spatial Scales

- Fault data
  - Typically cover average slip rates over millions of years
  - Serve to provide a realistic geometry for models as well as estimates of present day fault slip rates
- Seismicity data show patterns that indicate active or potentially active regions or faults
- Spaceborne geodetic data
  - Deformation rates between earthquakes
  - Amounts of slip as a result of earthquakes
- Global Positioning System (GPS) data
  - Collected at sparsely located ground stations
  - Provide a nearly continuous time series of deformation
  - Indicate both secular and transient deformation characteristics



- Interferometric Synthetic Aperture Radar (InSAR)
  - Spaceborne and airborne (UAVSAR) platforms
  - Provide spatially continuous images of surface deformation in between and due to earthquakes

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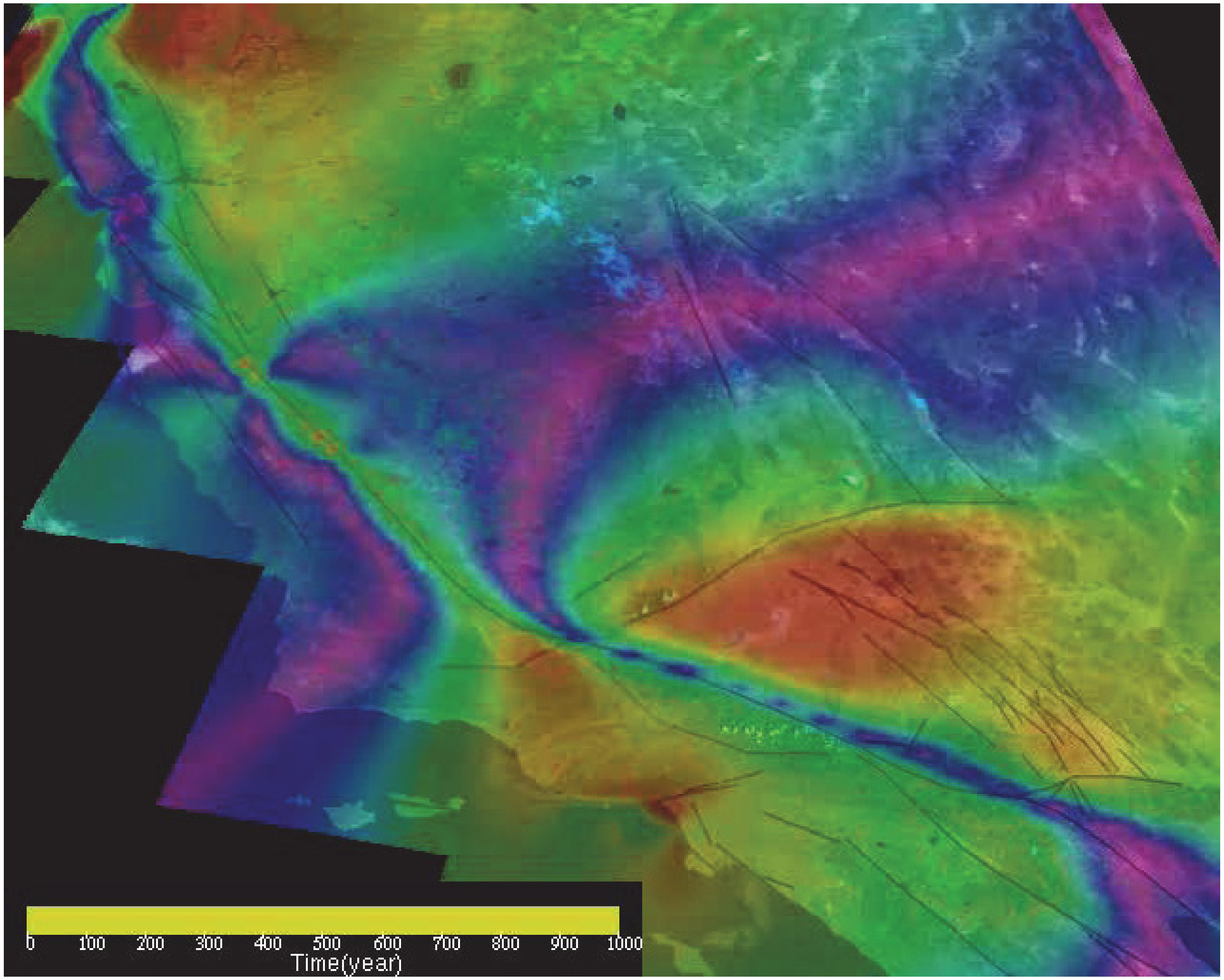
Need to Understand Fault Interactions



- Study correlations between events
- San Andreas events typically follow, but do not precede Eastern California Shear Zone Events
- Southern California long faults tend to follow Baja Earthquake type events

1000 years of simulated earthquakes

Earthquake Forecasting

- Pattern informatics of seismicity data
- 78% success rate
- Four cities forecast in Japan indicated Sendai and Tokyo areas highest likelihood for an earthquake
- Tokyo area has increased since the March 11 M 9.0 earthquake

Scorecard

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Focusing Attention on Future Earthquake Likelihood

November 2007 Abstract in proposal to NASA:

We propose to observe seismically and tectonically active regions in northern and southern California using UAVSAR to support EarthScope activities. We will test the earthquake forecasting methodology developed by Rundle through NASA's QuakeSim project by observing regions indicated as having high probability for earthquakes in the near future (5–10 years). The UAVSAR flights will serve as a baseline for pre-earthquake activity. Should an earthquake occur during the course of this project, we will also be able to observe postseismic motions associated with the earthquakes.

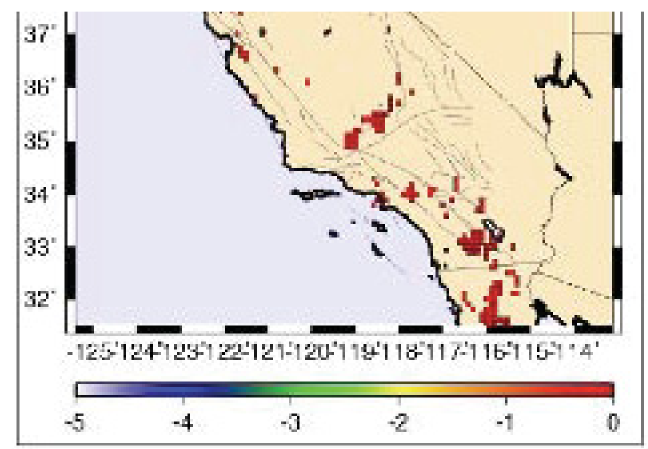
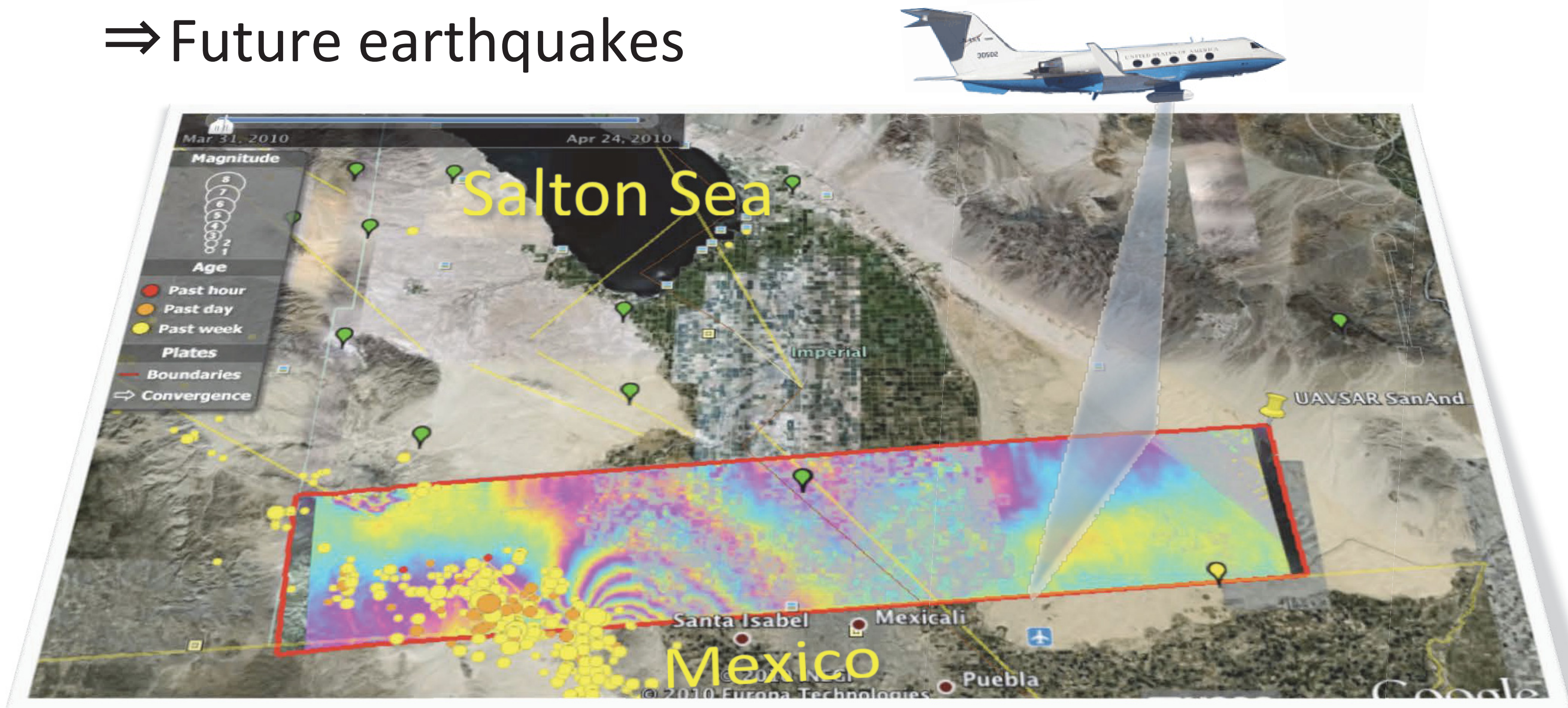


Figure 1. Pattern informatics (PI) map for the California and surrounding region cropped to better show the regions of interest in this proposal. Data from 1950–2005 were used. Map is a forecast of where earthquakes are expected to occur during a future time window of 5–10 years. Color figure from Holliday et al., 2007.

First UAVSAR Measurement of an Earthquake

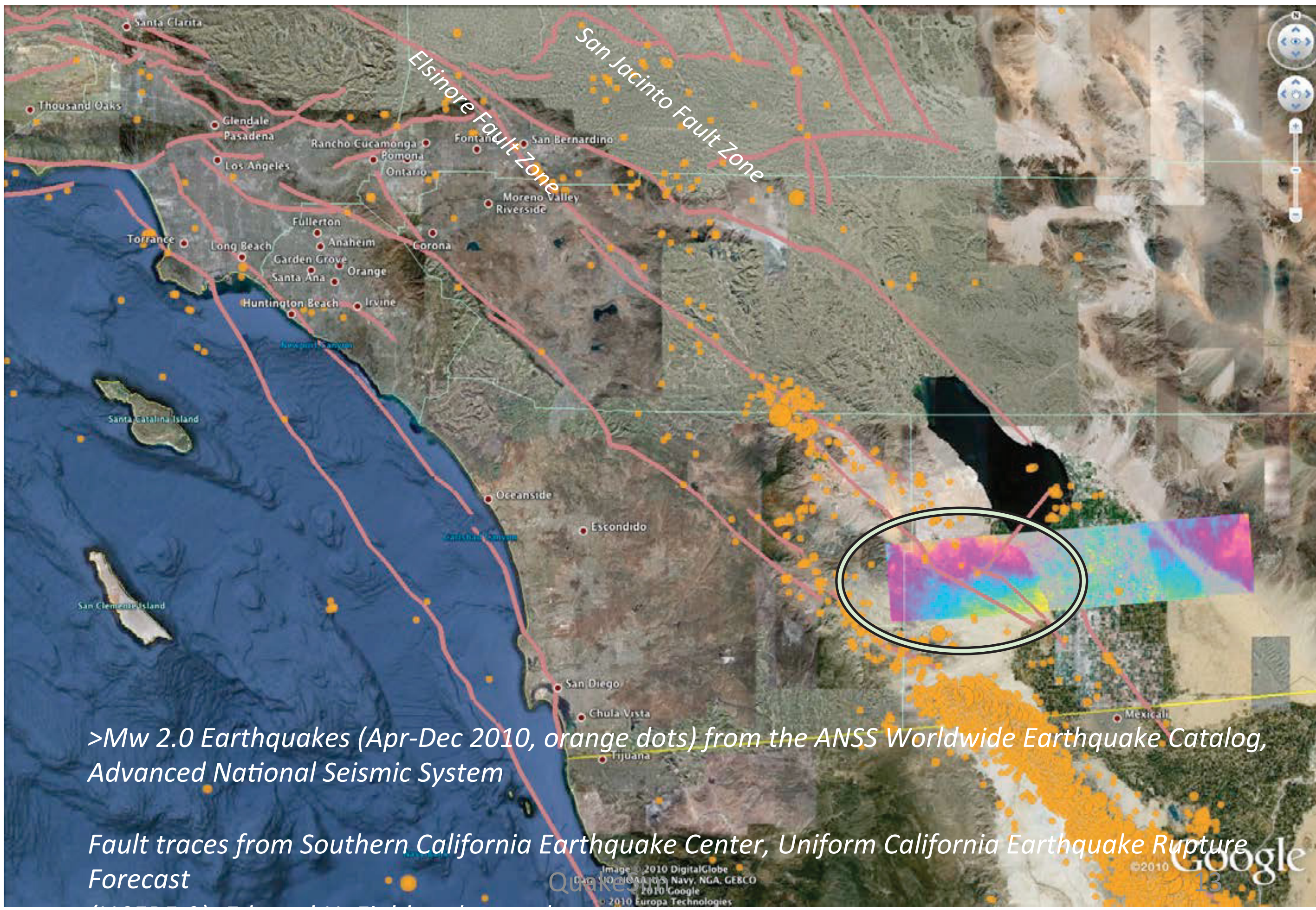
- **Response:** Displacement and disturbance maps
- **Forecasting:** Strain migration

  ⇒Future earthquakes



Quake Triggers Responses on Key Faults

- Elsinore fault extends into Los Angeles (nearly all is historically quiet: building stress)
- San Jacinto fault reaches to San Bernardino (historic quakes are >100 yr or far south)
- Full-length ruptures must be considered: damaging earthquakes

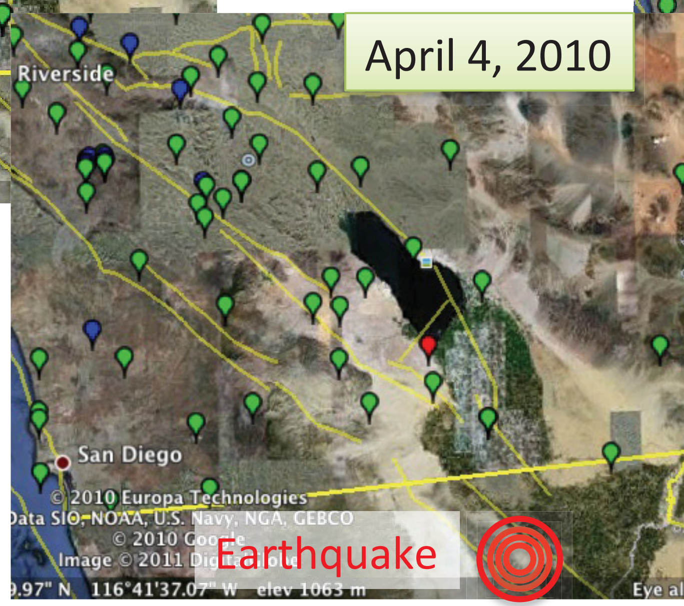


>Mw 2.0 Earthquakes (Apr-Dec 2010, orange dots) from the ANSS Worldwide Earthquake Catalog, Advanced National Seismic System

Fault traces from Southern California Earthquake Center, Uniform California Earthquake Rupture Forecast

GPS Time Series State Changes

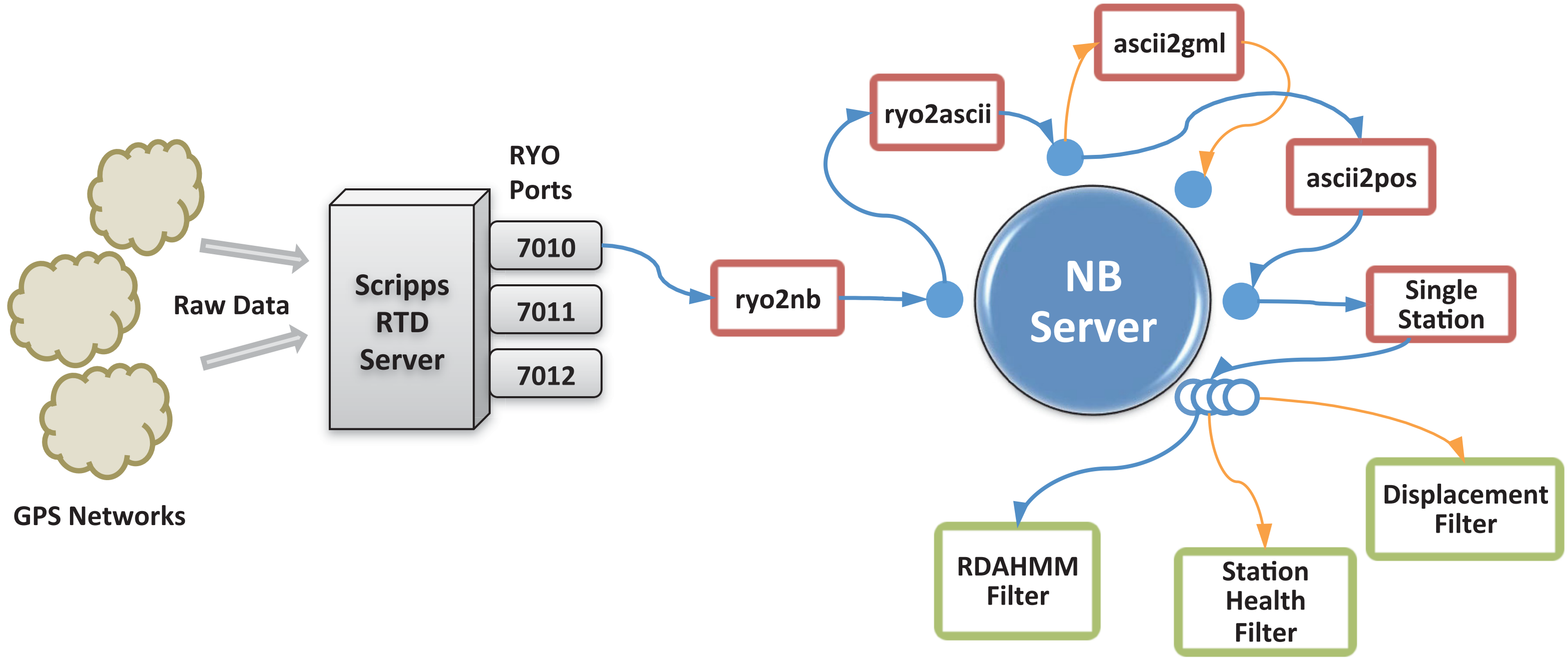
Regularized Deterministic Annealing Hidden Markov Model (RDHAMM)

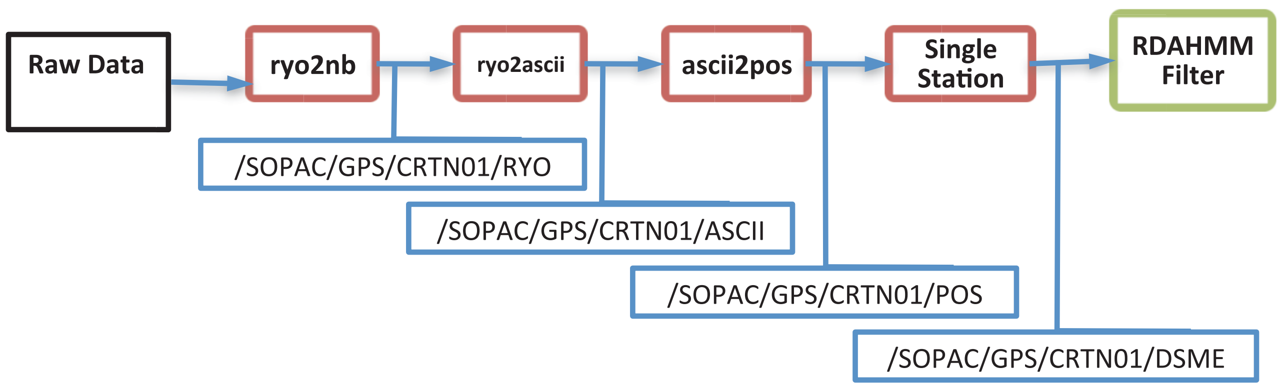


Developed by
Robert Granat, JPL

Triggered slip on other faults is observed by geologists and shows up in GPS station time series

Processing Real-Time GPS Streams

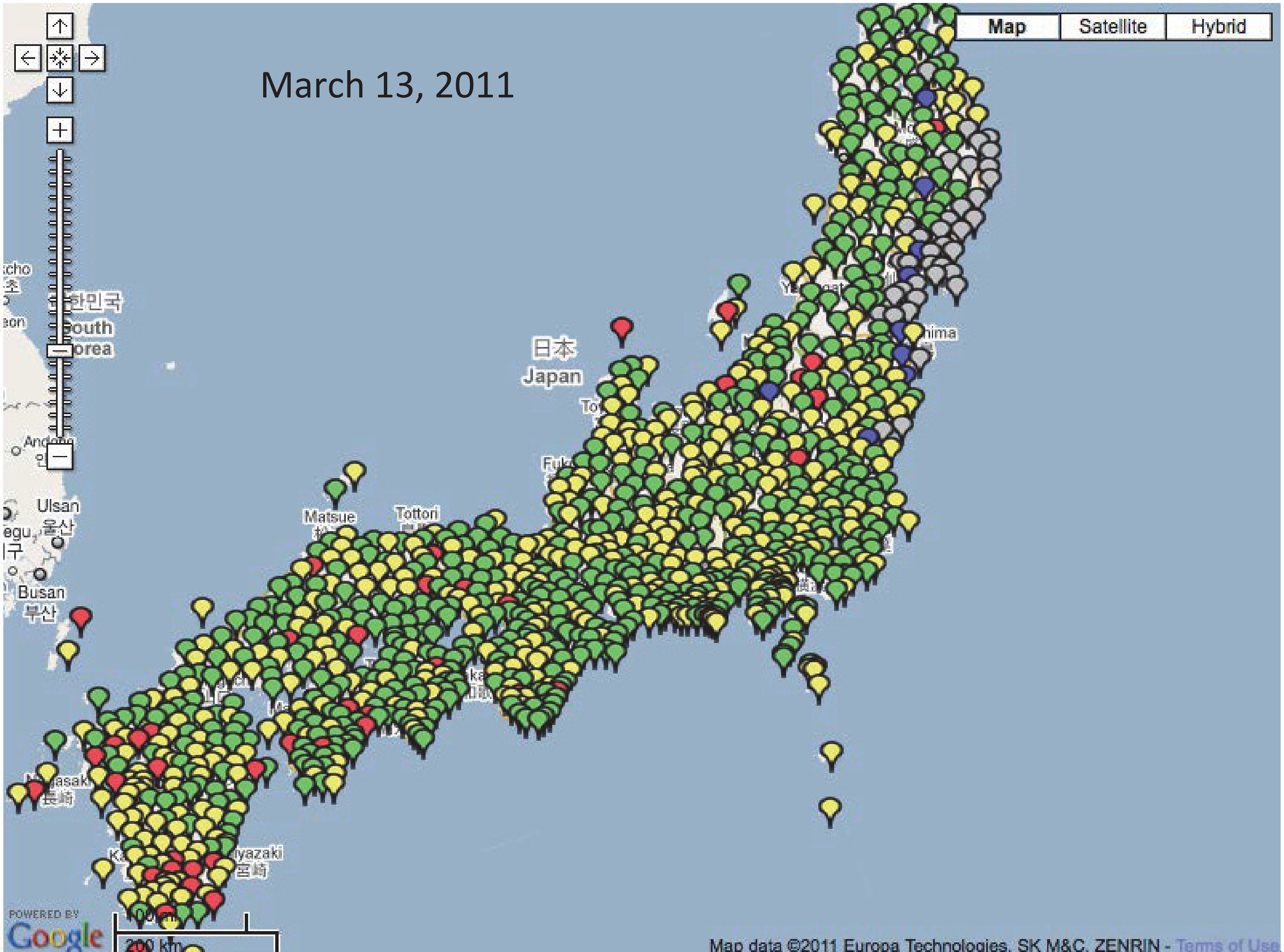




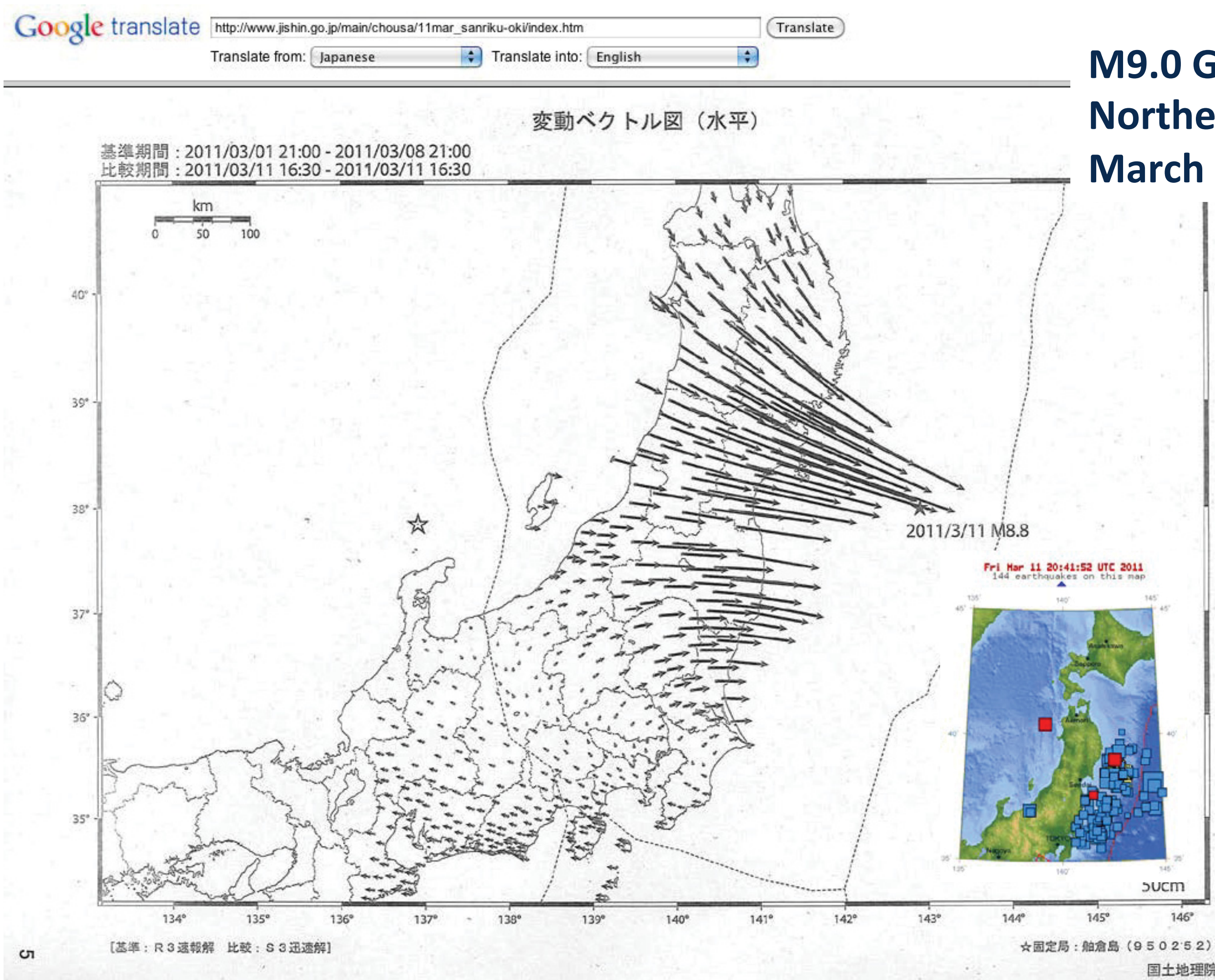
Broker and services replicated in the cloud

A Complete Sensor Message Processing Path, including a data analysis application.

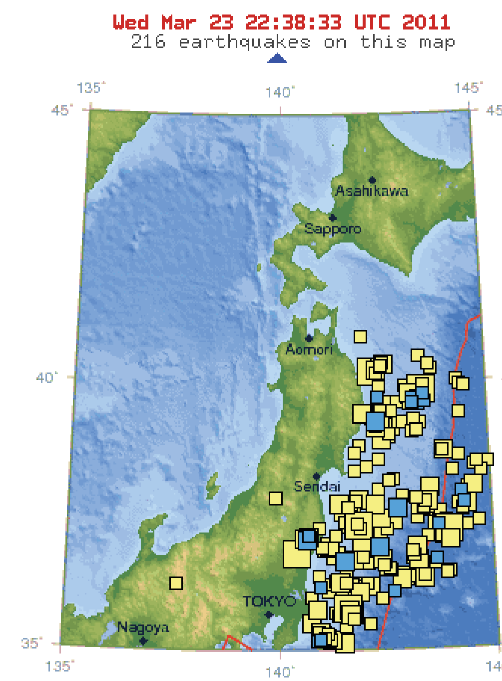
GPS Time Series Analysis for Japan



Ensure Standard Formats for Data Sources and Output so that Different Systems can Ingest the Data



M9.0 Great Tohoku Earthquake
Northeast Honshu, Japan
March 11, 2011



Geographic Survey Institute, Japan (GSI) GPS Solutions

Ensure Standard Formats for Data Sources and Output so that Different Systems can Ingest the Data

M9.0 Great Tohoku Earthquake
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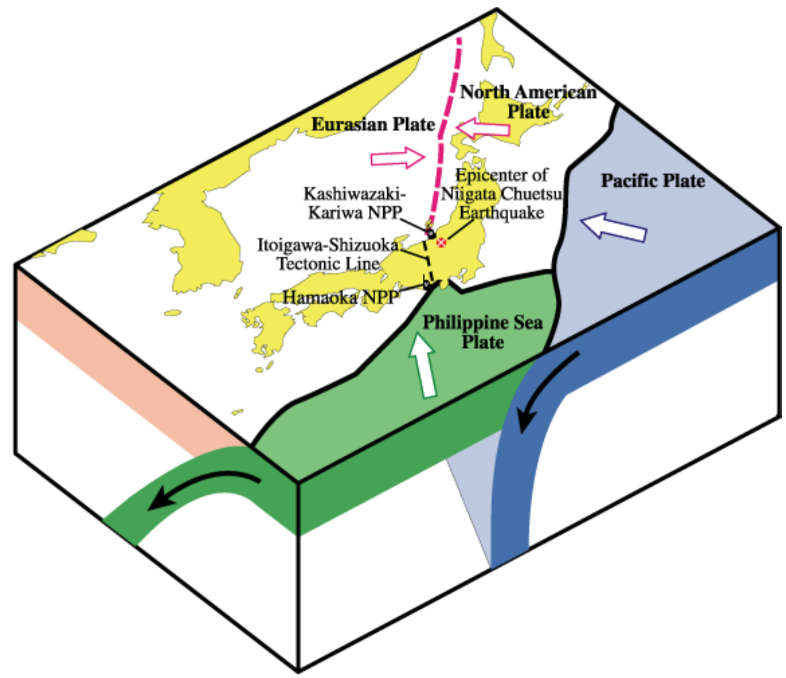


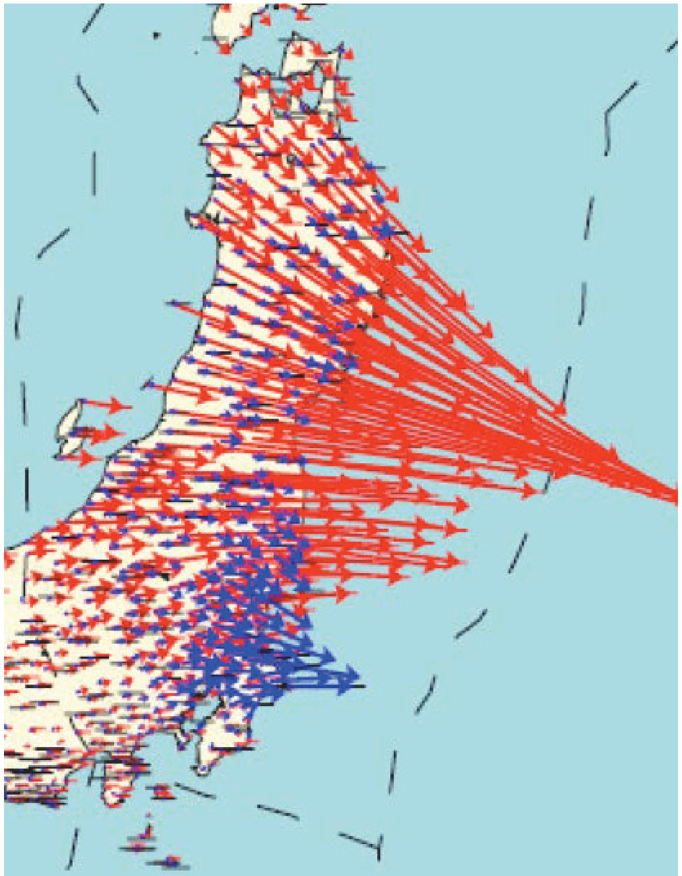
Geographic Survey Institute, Japan Data

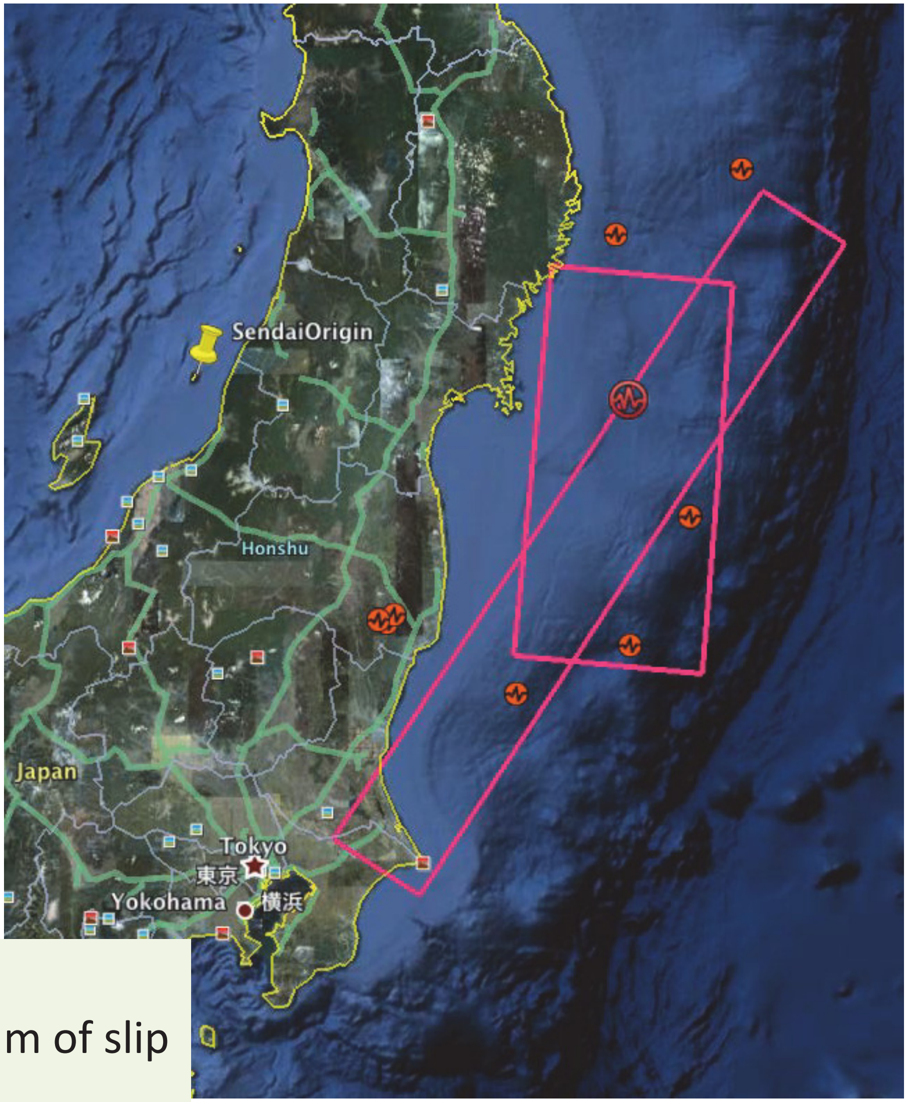
JPL GSI GPS data solution

Manual input to slip inversions

Construct finite element model for understanding stress transfer

M 9.0 Tohoku Earthquake Slip Inversions





Coseismic model
120 by 249 km fault patch; Nearly 23 m of slip
Postseismic model
65 by 494 km fault patch; 1.3 m of slip

QUAKESIM

The Good, the Bad, and the Ugly

- Leverages work to produce more science

Good

- Mistrust
  - Scientists often want to hold their data or tools

Ugly

- Duplicative work
  - Healthy competition often adds validation and exposes occasional errors

Good

  - Inefficient and sometimes ends up with misleading credit

Bad

- Need clearly defined roles and interfaces

Good

At this the whole pack rose up into the air, and came flying down upon her

– Alice in Wonderland

Infrastructure for Today and the Future

- Data deluge will continue to increase
  - Increasing diversity of data sets and sources
  - Including from future missions
- Groups should produce data products that can be readily integrated into other systems
  - Modeling and analysis
  - Decision support

Grids, clouds, and interfaces will become increasingly important